# An Introduction to Automotive LIDAR

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# An introduction to automotive light detection and ranging (LIDAR) and solutions to serve future autonomous driving systems.

LIDAR – sometimes called time of flight (ToF), laser scanners or laser radar – is a sensing method that detects objects and maps their distances. The technology works by illuminating a target with an optical pulse and measuring the characteristics of the reflected return signal. The width of the optical pulse can range from a few nanoseconds to several microseconds.

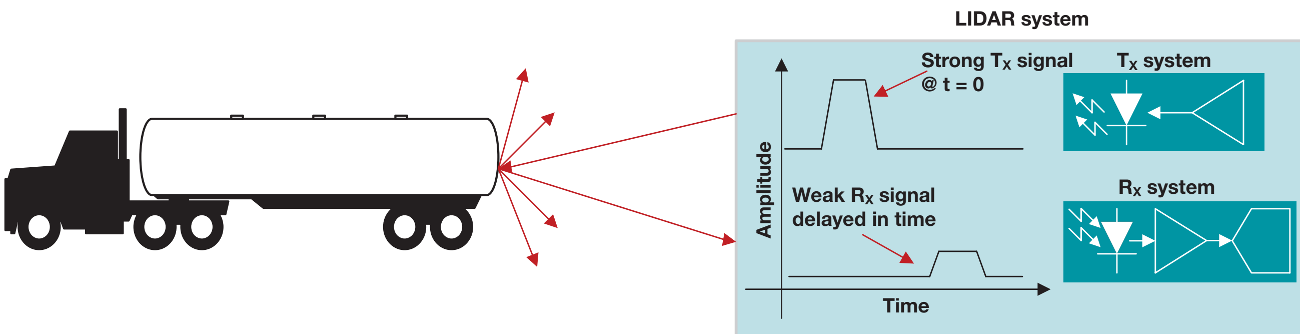


***Figure 1.*** *Pulsed ToF-based LIDAR system.*

**Figure 1** shows the basic principle of LIDAR, with light shining out in certain patterns and information extracted based on the reflections gathered at the receiving end. Pulse power, round-trip time, phase shift and pulse width are common parameters used to extract information from light signals.

Why choose light? What differentiates LIDAR from other existing technologies such as radar, ultrasonic sensors or cameras? What's driving the hype around LIDAR? In this white paper, we will address these questions in the context of long-range LIDAR, which is going to be an important sensor for autonomous driving. In addition to autonomous vehicles, LIDAR has applications in 3D aerial and geographic mapping, safety systems in factories, smart ammunition and gas analysis.

## Detection and imaging in autonomous cars

Manufacturers are outfitting modern cars with a wide array of advanced control and sensing functions. Collision warning and avoidance systems, blind-spot monitors, lane-keep assistance, lane-departure warning and adaptive cruise control are examples of established features that assist drivers and automate certain driving tasks, making driving a safer and easier experience.

LIDAR, radar, ultrasonic sensors and cameras have their own niche sets of benefits and disadvantages. Highly or fully autonomous vehicles typically use multiple sensor technologies to create an accurate long- and short-range map of a vehicle's surroundings under a range of weather and lighting conditions. In addition to the technologies complementing each other, it is also important to have sufficient overlap in order to increase redundancy and improve safety. Sensor fusion is the concept of using multiple sensor technologies to generate an accurate and reliable map of the environment around a vehicle.

Ultrasonic waves suffer from strong attenuation in air beyond a few meters; therefore, ultrasonic sensors are primarily used for short-range object detection.

Cameras are a cost-efficient and easily available sensor; however, they require significant processing to extract useful information and depend strongly on ambient light conditions. Cameras are unique in that they are the only technology that can "see color." Cars that have the lane-keep assist feature use cameras to achieve this feat.

LIDAR and radar share a broad array of common and complementary features that can map surroundings as well as measure object velocity. Let's compare the two technologies in several categories:

- **Range.** LIDAR and radar systems can detect objects at distances ranging from a few meters to more than 200 m. LIDAR has difficulty detecting objects at close distances. Radar can detect objects from less than a meter to more than 200 m; however, its range depends on the type of system:
  - Short-range radar.
  - Medium-range radar.
  - Long-range radar.
- **Spatial resolution.** This is where LIDAR truly shines. Because of its ability to collimate laser light and its short 905- to 1,550-nm wavelength, infrared (IR) light spatial resolution on the order of 0.1 degrees is possible with LIDAR. This allows for extremely high-resolution 3D characterization of objects in a scene without significant back-end processing. On the other hand, radar's wavelength (4 mm for 77 GHz) struggles to resolve small features, especially as distances increase.
- **Field of view (FOV).** Solid-state LIDAR and radar both have excellent horizontal FOV (azimuth), while mechanical LIDAR systems, with their 360-degree rotation, possess the widest FOV of all advanced driver assistance systems (ADAS) technologies. LIDAR has better vertical FOV (elevation) than radar. LIDAR also has an edge over radar in angular resolution (for both azimuth and elevation), which is one key feature necessary for better object classification.
- **Weather conditions.** One of the biggest benefits of radar systems is their robustness in rain, fog and snow. The performance of LIDAR generally degrades under such weather conditions. Using IR wavelengths of 1,550 nm helps LIDAR achieve better performance under adverse weather conditions.
- **Other factors.** LIDAR and cameras are both susceptible to ambient light conditions. At night, however, LIDAR systems can have very high performance. Radar and modulated LIDAR techniques are robust against interference from other sensors.
- **Cost and size.** Radar systems have become mainstream in recent years, making them highly compact and affordable. As LIDAR has gained in popularity, its cost has dropped precipitously, with prices dropping from approximately US$50,000 to below US$10,000. Some experts predict that the cost of a LIDAR module will drop to less than US$200 by 2022.
- The mainstream use of radar in modern-day cars is made possible by increased integration, which reduces system size and cost. The mechanical scanning LIDAR system from a few years ago – commonly seen mounted, for example, atop Google's self-driving car – is bulky, but advances in technology have shrunk LIDAR over the years. The industry shift to solid-state LIDAR will further shrink system size.

## LIDAR types

Among the different types of LIDAR systems available, in this paper we will focus primarily on the narrow-pulsed ToF method. There are two types of beam steering in LIDAR systems:

- Mechanical LIDAR uses high-grade optics and a rotating assembly to create a wide (typically 360-degree) FOV. The mechanical aspect provides a high signal-to-noise ratio (SNR) over a wide FOV, but results in a bulky implementation (although this has also been shrinking).

- Solid-state LIDAR has no spinning mechanical components and a reduced FOV; thus, it is cheaper. Using multiple channels at the front, rear and sides of a vehicle and fusing their data creates an FOV that rivals mechanical LIDAR.

Solid-state LIDARs have multiple implementation methods, including:

- **Microelectromechanical systems (MEMs) LIDAR.** A MEMS LIDAR system uses tiny mirrors whose tilt angle varies when applying a stimulus such as a voltage. In effect, the MEMS system substitutes mechanical scanning hardware with an electromechanical equivalent. The receiver light collection aperture that determines the receive SNR is typically quite small (a few millimeters) for MEMS systems. To move the laser beam in multiple dimensions requires cascading multiple mirrors. This alignment process is not trivial, and once installed, it is susceptible to shocks and vibrations typically encountered in moving vehicles. Another potential pitfall with a MEMS-based system is that automotive specifications start at –40°C, which can be challenging for a MEMS device.
- **Flash LIDAR.** Flash LIDAR operation is very similar to that of a standard digital camera using an optical flash. In flash LIDAR, a single large-area laser pulse illuminates the environment in front of it and a focal plane array of photodetectors placed in close proximity to the laser captures the back-scattered light. The detector captures the image distance, location and reflected intensity. Since this method captures the entire scene in a single image compared to the mechanical laser scanning method, the data capture rate is much faster. In addition, since the entire image is captured in a single flash, this method is more immune to vibration effects that could distort the image. A downside to this method is the presence of retroreflectors in the real-world environment. Retroreflectors reflect most of the light and back-scatter very little, in effect blinding the entire sensor and rendering it useless. Another disadvantage to this method is the very high peak laser power needed to illuminate the entire scene and see far enough.
- **Optical phase array (OPA).** The OPA principle is similar to phased-array radar. In an OPA system, an optical phase modulator controls the speed of light passing through the lens. Controlling the speed of light enables control of the optical wave-front shape, as shown in **Figure 2**. The top beam is not delayed, while the middle and bottom beams are delayed by increasing amounts. This phenomenon effectively "steers" the laser beam to point in different directions. Similar methods can also steer the back-scattered light toward the sensor, thus eliminating mechanical moving parts.

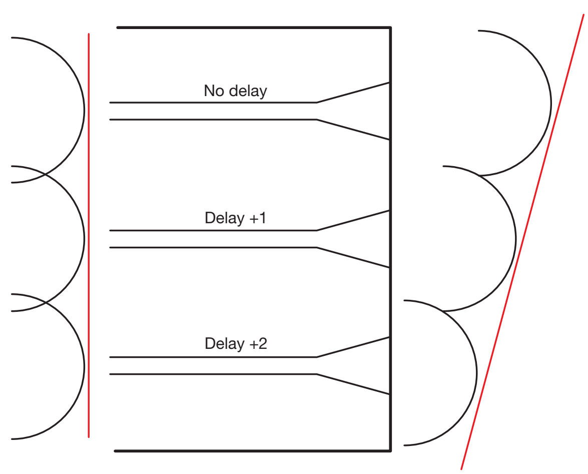


***Figure 2.*** *An OPA.*

- **Frequency-modulated continuous wave (FMCW) LIDAR.** While the methods listed so far are based on the ToF principle using narrow light pulses, FMCW LIDAR uses a coherent method, producing brief chirps of frequency-modulated laser light. Measuring the phase and frequency of the return chirp enables the system to measure both distance and velocity. The computational load and optics are a lot simpler with the FMCW method, although the chirp generation adds complexity.

## The LIDAR subsystem

**Figure 3** shows the entire functional LIDAR subsystem, including the signal chain, power, interface, clocking and monitor/diagnostics subsystem. The main subsystems of the LIDAR signal chain comprise a transmitting system (Tx), a receiving system (Rx) and a custom digital-processing system to extract point-cloud information. TI offers device options for the function blocks shown in teal.

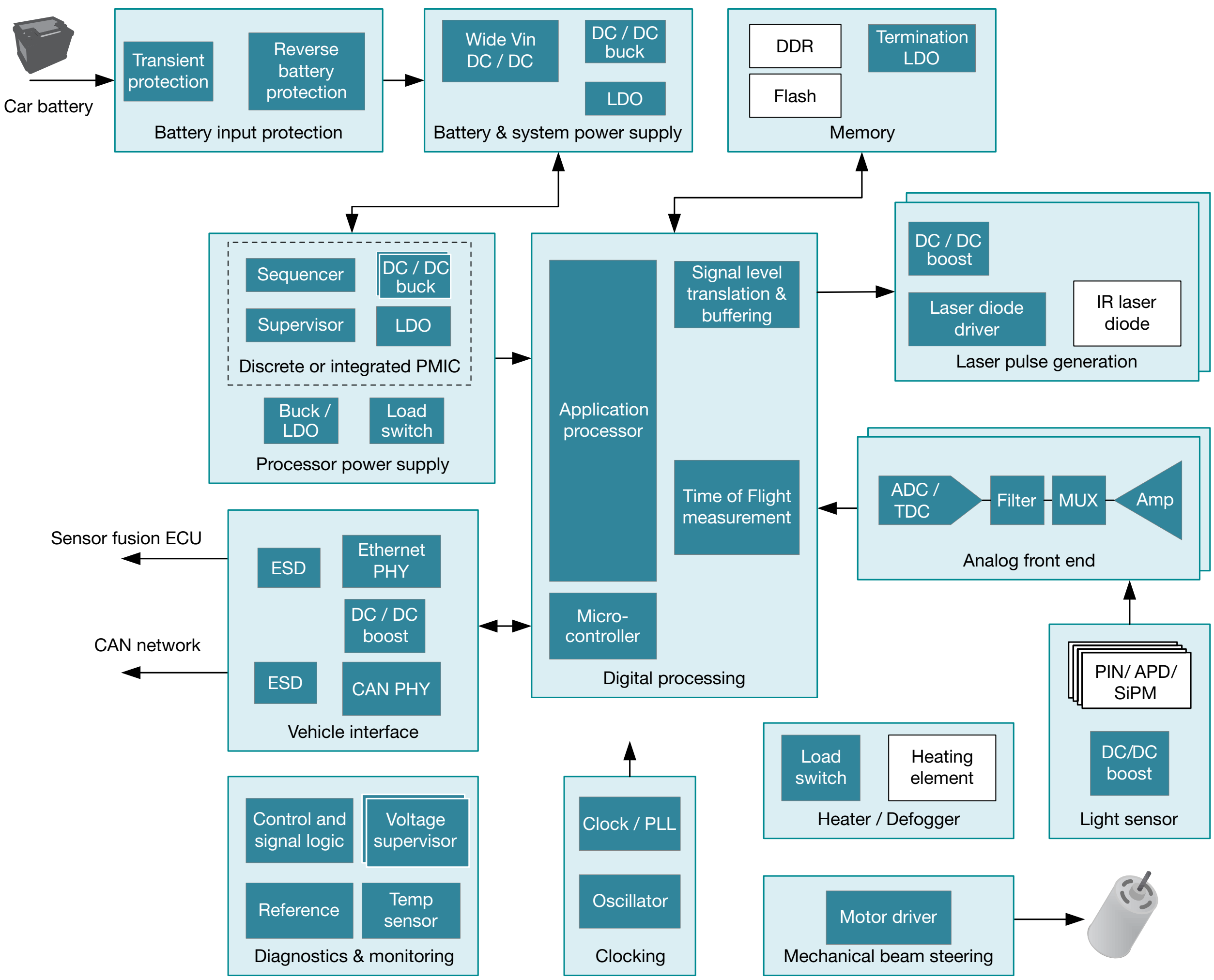


*Figure 3. LIDAR subsystem showing signal chain, power, interface, clocking and monitor/diagnostics subsystem.*

## Summary

The world is embarking on a new and exciting journey toward the commercialization of autonomous cars, and the technologies and architectures fueling this space are in a constant state of flux. LIDAR is a relative newcomer to this arena, but the advantages that this technology offers are spurring rapid innovation as it plays catch-up with more established sensor systems.

## Additional resources

- Check out TI's ADAS applications and TI reference designs.
- Explore TI's portfolio of automotive-qualified high-speed operational amplifiers, high-speed analog-to-digital converters and temperature sensors.
- Read these related white papers:
  - "Making cars safer through technology innovation."
  - "Scalable electronics driving autonomous vehicle technologies."
  - "Paving the way to self-driving cars with advanced driver assistance systems."

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